Integration of Marine Mammal Movement and Behavior into the Effects of Sound on the Marine Environment

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LONG-TERM GOALS

Integration of the Marine Mammal Movement and Behavior (3MB) model into the Effects of Sound on the Marine Environment (ESME) program contributes to the ultimate goal of creating an environmental assessment tool for activities that introduce high levels of sound into the ocean, particularly activities of the U.S. Navy.

OBJECTIVES

The objectives of the effort are to 1) expand the species library available for use in 3MB, 2) continue incorporating the ability to project environmental influences on simulated animal (animat) movement, 3) compare the animat implementation in environmental assessment procedures with static distribution approaches, and 4) incorporate the ability to emulate an animal's vocal behavior within the animat representation.

APPROACH

The proposed augmentation consists of several tasks, some of which will be completed in collaboration with Boston University (BU), Heat Light and Sound, Inc. (HLS) and Portland State University (PSU). Task 1 involves a continuing effort to acquire data for use in the development of species libraries. Task 2 involves a continuing enhancement of the 3MB model to permit better representation of the effects of environmental factors on marine mammal behavior. Task 3 is a quantitative assessment of the differences in impact estimates that result from the use of static animat distributions in simulated acoustic exposure scenarios and the use of animats (i.e. automatons that are mobile in space and time). Task 4 involves implementing the capability to have animats vocalize, thus providing ESME with a first step toward enabling the evaluation of passive acoustic mitigation measures.

Task 1 – Species Library Development
Development of species definitions (i.e. animats) requires access to information on the dive behavior and movement of marine mammals. A limited database of species definitions has been created based on the scientific literature available for certain species. This database will continue to be developed by first implementing information available in the literature for other species. The priority of species definition construction will be determined based on the quality of the data reported in the available

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literature and the likelihood of the marine mammal species' occurrence in areas of US Navy concern (e.g. training ranges). Information sought will consist of statistical descriptions of dive depth, foraging dynamics at depth, vertical and horizontal swim rates, and temporal variations in dive behavior.

Task 2 – Environmental Influences on Animat Behavior
Currently, 3MB permits bathymetric characteristics to influence animal distribution and behavior. Depth limits on the initial distribution of animats and on the water depths that an animal might move into during a simulation are established in the creation of the species definitions. Additional environmental influences over behavior can be accounted for, such as diel and bathymetric control of behavior state transitions and options, slope aggregation, convergence on oceanographic features, etc. Initial enhancements will consist of modifying the transition probability matrices of the animats to include diel variability in behaviors and behavioral transitions. Follow-on enhancements will attempt to incorporate attraction/repulsion to or from environmental features. The most likely approach for enabling this behavior in animats would be through vector representation of oceanographic features (e.g. temperature gradients) which can then be used as weight in the animat directional movement algorithm.

Task 3 – Compare Outcome of Static Distribution and Animat Modeling Approaches
Historically, estimates of impact to marine mammals resulting from Navy acoustic activities have relied on 2-dimensional models of transmission loss from sources, and static distributions of animals with little regard for animal movement in the vertical and horizontal dimensions. Alternative analyses have attempted to improve on the realism of impact estimates through the implementation of 3-dimensional transmission loss calculations and either 3-dimensional static distributions of animals (i.e. accounting for dive behavior) or the implementation of animat behavior, the latter being a 4-dimensional approach (i.e. animat behavior varies in time). Each of these approaches presumably affects the predicted impact to marine mammals due to the underlying assumptions that are applied. However, a systematic investigation of the variation in the magnitude of the approach-dependent quantitative estimate has yet to be made. In collaboration with HLS and PSU, Biomimetica will create several species that can be used to address each of the modeling approaches described above. Simulations will be run on a range independent environment using both a static sound source and a mobile sound source with a set duty cycle. Impacts will be calculated for different types of marine mammals crudely categorized as deep, mid or shallow water divers. Results of the study will be published in a journal with an environmental modeling focus.

Task 4 – Animat Vocalization
Interest in enabling animats to vocalize has recently arisen because of a desire to test the feasibility and effectiveness of passive acoustic mitigation measures. The purpose of this capability is to provide a means for passive acoustic detection methods to be tested via simulation and to determine which methods demonstrate the most promise for implementation in the real world. Furthermore, simulation capabilities are desired that permit acoustic detection methods to be related to visual detections in the estimation of the abundance and distribution of marine mammals. This task would involve the enabling of vocalizations by animats with a focus on species-specific vocal patterns.

Communication with bioacoustics researchers will be undertaken to obtain samples of underwater marine mammal phonations which can be attached to an individual animat. Acoustic data files will also be obtained from data repositories (e.g. Cornell Macaulay Library of Natural Sounds) and other facilities with access to marine mammal sound archives (e.g. ONR). Data files will be standardized (i.e. re-sampled and adjusted for resolution) for use in the ESME model. Where possible, species-

specific information on phonation rates will be used to determine probabilistic models of sound production and will be incorporated as part of the animat's behavioral definition.

WORK COMPLETED

The Navy One-Model approach to acoustic impact analysis required integration of the ESME effort with that of the US Navy. As a result, certain task requirements were placed on hold so that personnel could assist the Naval Undersea Warfare Center (NUWC) with development of the One-Model approach, while assisting ESME team members with the development of a publicly available version of ESME that was an unclassified yet comparable version of the the Navy One-Model. Changes in task effort are reflected below.

Task 1 - The initial species library was completed in August, 2010. It includes the blue whale (*Balanoptera musculus*), fin whale (*Balaenoptera physalus*), Cuvier's beaked whale (*Ziphius cavirostrisis*), Blainsville's beaked whale (*Mesoplodon densirostris*), harbor porpoise (*Phocoena phocoena*), harbor seal (*Phoca vitulina*), sperm whale (*Physeter catodon*), bottlenose dolphin (*Tursiops truncatus*), California sea lion (*Zalophus californianus*), and northern elephant seal (*Mirounga angustirostris*). In addition, ocean-specific species variants were created for the harbor porpoise, sperm whale, and bottlenose dolphin, and gender specific variants were created for the sea lion and northern elephnat seal. Data for the elephant seal were obtained from Dr. Daniel E. Crocker of Sonoma State University and were analyzed for gender-specific parameter values. All other species definitions were derived from information in the peer-reviewed scientific literature.

Task 2 - Diel variability in dive behavior has been implemented into 3MB. The Species Builder program permits behavior transition matrices to be varied as a function of the time of day, thus permitting differences in nocturnal, diurnal, and corpuscular behaviors to be implemented. In addition, behaviors can be affected by a combinatorial process of time of day and depth, thus providing greater flexibility in designing animal behavior. Water depth (bathymetry) was added as an environmental attractor during the last quarter of calendar year 2010. The attractor works by having vector fields (defined by changes in depth over distance) influence the water depth selection of species defined as either shelf, slope, or pelagic. The bathymetry vector field is used in a combinatorial function with the animat's movemement vector to generate the desired directional swim behavior for the animat.

Task 3 - A manuscript comparing different methods of estimating marine mammal harassment from acoustic exposure was submitted to the journal Marine Environmental Research. The paper is currently in review. The paper compares harassment calculations using the static 3D distribution of animals in the environment (based on density and distributions of residency at depth) to dynamic simulations of marine mammals (the animat method). The model comparison, utilizing a synthetic shallow diving and deep diving species, demonstrates that the static distribution method consistently provides the lowest estimate of impact. In contrast, higher estimates are observed with animats because the dynamic approach accounts for the possibility that animals may be exposed more than once during a simulation, with the potential for differing exposure levels during each exposure. Furthermore, the animat approach provides measures of uncertainty, which are important in determining the confidence in the prediction, and allows estimates of the probability of spurious scenarios (i.e. high numbers of harassments) to be made.

Task 4 - An initial analysis of the signal parameters to be used in describing marine mammal vocalizations was performed. However, this task was placed on hold in order to shift effort toward the creation of the classified and unclassified (ESME) versions of the Navy One-Model for acoustic impact analysis.

Additional Work - The first public release of 3MB was made on October 31, 2009. The package contained both the 3MB simulator and the Species Builder software. The software was released with a User Guide, several bathymetry files, and generic species which could be used as references in the building of species. The program has been used and evaluated by several commercial organizations, both in the United States and Europe, that are involved in evaluating impacts of hman-made sound on marine mammals. Feedback from users was used to modify 3MB to better meet user needs.

Significant effort was placed into updating 3MB code for NUWC's integration of 3MB into the Navy One-Model. Dr. Dorian Houser assisted NUWC personnel throughout the period of performance in evaluating assesment/modeling methods and categorizing marine mammal species into clades by the amount of dive information available for each. In addition, the species library (see Task 1) was delivered to NUWC for incorporation and use in their model and the ability to seed simulated environments with NUWC provided shape files was completed. Through the conclusion of the program, additional effort was given to ensuring that NUWC programs interfaced correctly with 3MB and modifications to 3MB were coded in order to adopt Navy One-Model procedures for animat seeding from Navy marine mammal density data formats.

In addition to the accomplishments listed above, numerous enhancements to 3MB and the associated Species Builder have been made. Examples of these include: providing cumulative and simple probability displays of the user interface; allowing independent dive rates for the ascending and descending portion of reversals; allowing slope regions to be displayed on scenario maps; adding the option for implementing a Gaussian termination function for behavior state termination; incorporation of 'Alpha blending' to permit the visualization of multiple data types; improvements in the centroid control version of pod behaavior; and playback of animal behavior following the completion of a simulation.

RESULTS

Comparisons between the static distribution of animals in the environment for impact assessment and that using dynamic animats have demonstrated a notable difference in the levels of impact prediction provided by the two methods. The latter approach typically produces higher estimates and has the advantage of providing estimate variances and the ability to predict spurious events. The implementation of diel variability and bathymetric influences on dive behavior permits the differences between these methods to be more thoroughly explored since the static distribution method does not account for variation in dive behavior with respect to either time or environmental condition. The animat approach is limited in that it incurs greater computational costs. Methods to diminish computational costs while minimizing loss of fidelity are currently being explored.

The initial species database capitalized on the available literature. To increase the library, efforts to obtain raw data from primary investigators involved in marine mammal tagging need to be pursued. Often, these data do not appear in the literature for years following collection and are presented in a summary format that prevents detailed models to be developed.

IMPACT/APPLICATIONS

The integration of the ESME program with the capability to emulate the dive and movement behavior of marine mammals provides a significant advantage to modeling environmental impact than do historic approaches used in Navy environmental assessments (EA) and impact statements (EIS). Many previous methods have been statistical or pseudo-statistical approaches that estimate impact by reduction of animal distributions in time and space. Although such approaches may be suitable for range independent environments, they do not approximate the real world and may miss important features of animal behavior and may over- or underestimate impact. Marine mammal dive behavior and distribution are both influenced by the environment. By implementing animat dive behavior and movement, and having each animat respond to the environment and emulate behaviors according to the species they model, a more realistic assessment of impact can be obtained. Such assessments will have benefit to both the management of animal stocks and in providing relief from legal issues grounded on prior modeling assumptions and outcomes.

RELATED PROJECTS

None.

PUBLICATIONS

Scott Schecklman, Dorian Houser, Matthew Cross, Dan Hernandez, and Martin Siderius. 2011. Comparison of methods used for computing the impact of sound on the marine environment, Marine Environmental Research, **71:**342-350. [published]